HAPS Gateway Link in the 5850-7075 MHz and Coexistence with Fixed Satellite Service

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Abstract. *Gateway link is essential to connect HAPS platform to terrestrial based networks. This crucial link is incorporated in HAPS fixed service spectrum allocation in considerably high frequencies, renders the link for more attenuations by atmospheric gases, and rain effects, especially when the regional climate is not favorable. However, under the agenda item 1.20 of World Radio Conference-2012 (WRC-12) new HAPS allocation in the 5850-7075 MHz band is proposed. Although spectrum features are incomparably reliable, on the contrary, Fixed Satellite Service (FSS) uplink transmissions will have signal levels much higher than those in HAPS systems and have the potential for causing interference at the HAPS gateway receiver. In this article a key aspect of co-channel interference phenomena is investigated to facilitate optimum frequency sharing in the band in question. By proposing mitigation techniques and statistical method this generic prediction model enhances the capability of the HAPS spectrum sharing and provides flexibility in spectrum planning for different fixed services.*

Keywords

Co-channel interference, minimum coupling loss, carrier-to-interference ratio, interference mitigation techniques, Monte-Carlo approach.

1. Introduction

There are approximately 160 geostationary satellites currently operating for Fixed Satellite Service (FSS) in the C band frequency (4 – 6 GHz). It is commercially utilized to deliver distance-learning, telemedicine, disaster recovery, TV transmission, meteorological and earth observation services, and military services. The basic application of the FSS is for a feeder link of systems, which serve earth stations at fixed locations. In parallel, High Altitude Platform Station (HAPS) is a new type of communication stations, posted in the stratosphere layer to deliver communications autonomously to satellite and terrestrial stations[1]-[2]. It is expected that HAPS will provide wide area coverage, high data rate services, and favorable link budget [3]-[5]. Frequency allocations for HAPS in the fixed service were considerably high and recognized to be more susceptible to attenuation due to rain in the range of: 47.9 – 48.2 GHz, 47.2 – 47.5 GHz in global, and 31.0 – 31.3 GHz in the uplink, 27.5 – 28.35 GHz in the downlink for 40 countries worldwide [2]. There are some views that HAPS should use the high frequency bands of Ka and V bands, not only because they offer a large bandwidth, but because they are not congested. Ignoring the fact of spectrum efficiency of providing services widely to access and utilize the spectrum, which should be reflected into HAPS spectrum allocation, since some parts of the spectrum, are more reliable and useful than the others. Therefore, resolution 734 (Rev.WRC-07) invited the International Telecommunication Union (ITU) to identify two channels of 80 MHz each for gateway links for HAPS in the range from 5850 MHz to 7075 MHz [6].

Backwards to the spectrum sharing strategy between HAPS and FSS systems [7]-[9], one can conclude that the studies were based on the Worst Case (WC) prediction model, which can be expressed under the Minimum Coupling Loss (MCL) approach [10]. No wonder that HAPS had tight sharing constrains in terms of geographical separation and power limits driven from pessimistic worst-case scenario. This paper aims to improve the intersystem interference prediction model from the FSS earth station to the HAPS gateway station in the band 5850 – 7075 MHz, by providing a comprehensive theoretical and statistical model. In this article, the proposed model core idea is taking account of natural factors, possible mitigation schemes, and spectral power techniques [11] to enhance MCL approach in the initial stage of spectrum planning. A whole picture can then be treated as case-by-case and evaluated using Monte-Carlo approach [12] to judge HAPS frequency allocation.

The paper is arranged as follows; Section 1 proposes MCL calculations and assessments. In Section 2, schemes to mitigate the FSS interference are investigated, declaring the effect of antenna elevation angle, antenna height, and

Mask Discriminations (MD). Simulated deterministic and statistic results are discussed in Section 3. Finally, in Section 4, the conclusion is delivered.

2. Technical Compatibility

The convergence of certain newer technologies, such as HAPS is making it difficult to decide whether it should be allocated in the reliable bands or alternative higher frequencies. Identification of the spectrum which HAPS gateway link will share with FSS is governed by the technical and operational specifications of both systems as tabulated in Tab. 1. The analysis will be based on the assumption that difference in antenna azimuth between the two earth stations is 180° that produces a WC scenario as shown in Fig. 1.

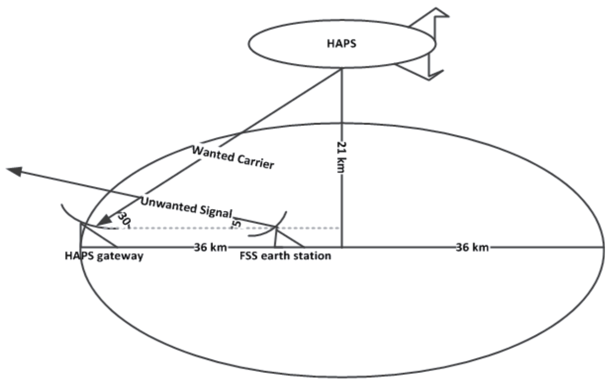

Fig. 1. Intersystem interference scenario between FSS earth station and HAPS gateway.

Subsequently, technical compatibility between FSS earth station and HAPS gateway is examined under the proposed Minimum Coupling Loss (MCL) approach, given by:

$$MCL = P_i + G_i(\varphi) - L_{ft} - I_{Th} + G_r(\theta) \quad (1)$$

where P_i represents the interfering FSS earth station transmitted power, $G_i(\varphi)$, and $G_r(\theta)$ are the antenna off-axis gain in the interfering path for interferer and victim, respectively, L_{ft} denotes the interferer transmission feeder loss, and I_{Th} is the interference threshold for the HAPS gateway receiver, which is given by:

$$I_{Th} = C - PR \quad (2)$$

where C is the HAPS downlink carrier in dBW [11], PR represents the victim receiver threshold of carrier-to-interference ration (C/I) of 27 dB for the 64-QAM link. From the above calculations, the resulted MCL value to ensure coexistence is 141.2 dB. Therefore, required separation distance translated from free space loss is given by:

$$d_{MCL_{km}} = 10^{\frac{MCL - 92.4 - 20\log(f_{GHz})}{20}}. \quad (3)$$

Parameter	Unit	FSS ES	HAPS
Transmitted power	dBW	35.56	-22:Airborne
Channel BW	MHz	36	11
Antenna height	m	15	21: Airborne 15: gateway
Antenna Elevation	o	5	30
Antenna gain	dBi	39.9	30: Airborne 47: Gateway
Feeder loss	dB	0.5	4.1

Tab. 1. FSS and HAPS systems parameters.

3. Mitigation Techniques

Spectrum engineering methods to mitigate severity of interference is applied to the intersystem interference scenario between HAPS and FSS earth stations. Under previous MCL, the scenario of coexistence between FSS and HAPS earth stations were carried pessimistically. For instance, the assumptions were such as the use of 5° elevation angle for the FSS earth station, applying Free Space Loss (FSL) propagation model, and ignoring the channelization plan and modulation schemes in the evaluation of interference between the communication systems. With these assumptions, planning spectrum might not be actual; therefore, variety of practical scenarios impacts are evaluated in this section:

3.1 FSS Elevation Angle

Definitely, it is not the actual case for the whole FSS earth stations to have such a low elevation angle; therefore, different locations in the world have to consider their real elevation angle, or otherwise statistic analysis should be used for general judgment. The characterization of the antenna is established to fit a defined radiation pattern; this representation appears as an envelope plot; which stands for a function of relative radiation. For a clearer explanation, FSS antenna radiation pattern follows the formula [13]:

$$G(\varphi) = \begin{Bmatrix} 32 - 25\log(\varphi) & for 2.6^{\circ} \le \varphi \le 48^{\circ} \\ \\ -10 & for 48^{\circ} \le \varphi \le 90^{\circ} \end{Bmatrix}. \quad (4)$$

Expectedly, there will be an additional loss in antenna gain relative to the described radiation pattern due to the use of higher elevation angle. To depict the loss as an advantage to the MCL ($G(5) - G(\varphi)$), Fig. 2 shows proportional relation between reduction in antenna gain (loss) and the increase in antenna elevation angle. When the reference envelop remains steady after 48°, hence the maximum loss is fixed to 24.5 dB. Noting that for those countries with actual 5° elevation angle (probably located in higher latitudes) this technique can be applied horizontally, but not vertically.

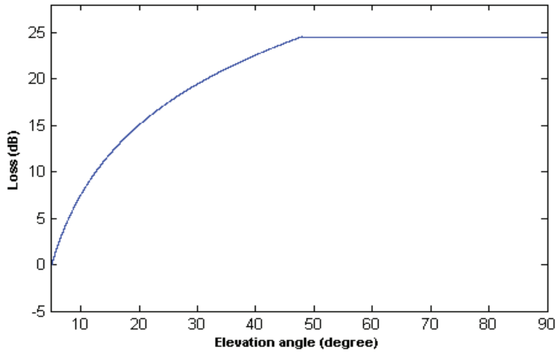

Fig. 2. Additional loss due to higher FSS earth station elevation angle.

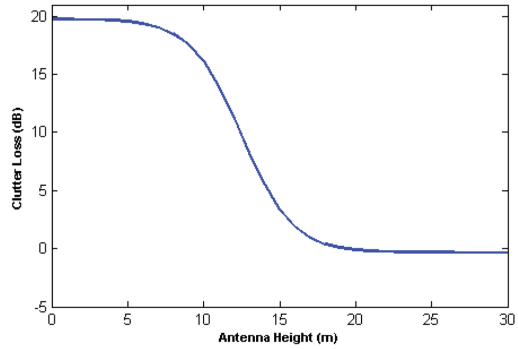

Fig. 3. Clutter loss effect for different antenna heights in UAC.

3.2 HAPS Gateway Antenna Height

Second is taking advantage of local topology and use a minimum acceptable antenna height to minimize the Line-of-Sight (LOS) between the earth stations. Different antenna heights have the potential to affect the required physical isolation; lowering the antenna height will reduce the required physical isolation dramatically [14]. Meanwhile, the protection from local clutter can be estimated using:

$$A_h = 10.25e^{-d_k}\left\{1-\tanh\left[6\left(\frac{h_v}{h_a}-0.625\right)\right]\right\}-0.33 \quad (5)$$

where d_k is the distance in km from a nominal clutter point, h_v is the antenna height in meters (m) above the local ground level, and h_a is the nominal clutter height in meters (m). Since deployment area for HAPS gateway is specified as an Urban Area Coverage (UAC), thus, UAC model is more convenient to predict the propagated interfering signal rather than deterministic FSL used in the MCL. The depicted UAC clutter loss in Fig. 3 summarizes the relationship between HAPS gateway antenna height and the corresponding clutter loss in dB.

If the antenna height is above 20 m, the clutter loss remains constant and a zero advantage can be considered. However, when antenna height is small, the line of sight toward the victim receiver may not be clear, meaning that interference power level is less due to obstacles. This indicates that attenuation of the interfering signal is decreased when the antenna height increases; thus, the antenna explores a greater interference level when its height increases.

3.3 Spectral Decoupling

Due to the imperfect radio equipments, transmitter Out-of-Band (OoB) leaks to fall within the pass-band or selectivity of the victims receive filter [15]. Therefore, interferer transmitter Spectrum Emission Mask (SEM) and victim receiver Adjacent Channel Selectivity (ACS) are significant to assess the intersystem interference estimation. The proposed masks and the channels overlapping are presented in Fig. 4 when the difference in the intermediate frequencies is set to zero ($\Delta f = 0$). In this case, the spectral decoupling can be estimated as follows,

$$SD(\Delta f) = -10\log\left(BW_{FSS} / BW_{HAPS}\right) \quad (6)$$

where BW_{FSS}, and BW_{HAPS} are the channel bandwidth of the FSS and HAPS carriers, respectively. This phenomena can be described as Mask Discrimination (MD) [16], or bandwidth correction factor [17]. The considered scenario of ($\Delta f = 0$) upshots an advantage loss value of 5.15 dB from the FSS earth station power; the logic behind this value is the difference in channelization plans. In other words, 11 MHz victim receiver channel will not fully integrate with the transmitting interferer of a 36 MHz channel. Some power is wasted.

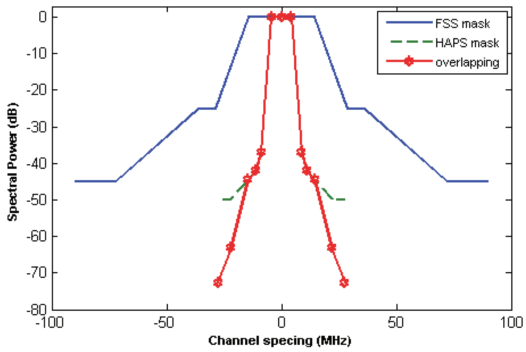

Fig. 4. Spectral power decoupling between FSS and HAPS systems earth stations.

4. Results and Discussions

Corresponding to the MCL model proposed in Section 2, the results are organized to show deterministic results of FSS antenna off-axis angle, and HAPS gateway antenna height, followed by statistical results that are derived using a random parameter generator for variables representing the mitigation schemes of HAPS antenna height and FSS elevation angle values.

4.1 Deterministic Results

Here, the pessimistic result of 42 km geographical isolation as estimated by the MCL approach (derived formulas (1) to (3)) is a subject of enhancement. As a result of setting coordination for sharing between HAPS and FSS ground stations, the required MCL geographical isolation is reduced; due to contribution of losses from elevation angle's effects, clutter loss effects, and MD, which are shown in the following plots.

Fig. 5 and Fig. 6 are concerned in determining the required separation distances that justify the victim receiver's PR threshold for the co-channel coexistence scenario. In this scenario, initial contribution loss is the MD of 5.15 dB, followed by advantages from the proposed mitigation techniques. Starting with the 0 dB losses, approximately a 22 km separation is required for 5° FSS elevation angle, and 20 m HAPS gateway antenna height, presenting a worst-case in coordination. This result shows the importance of considering the MD, which reduced the required distance to the half, approximately. Therefore, consideration of different systems channelization plans enhances the opportunity of achieving optimistic sharing constrains.

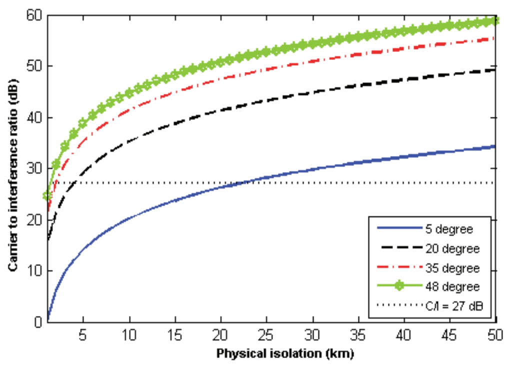

Fig. 5. Separation distance for different elevation angles.

Increasing the offset from the main beam of the FSS as shown in Fig. 5, moves the radiation pattern peak away from the interference path towards the HAPS gateway; thus lower latitude locations gain a natural advantage of high elevation angle. Additional loss of 15 dB and 21 dB is created after 20° and 35° elevation angle, results in a 4 km and 2 km physical isolation, respectively. By the 48° elevation angle or even higher, FSS attains its far sidelobe level; and thus a steady loss of 24.5 dB reduces the separation distance to 1.4 km only.

When the HAPS antenna height increases as shown in Fig. 6, interference from the FSS gateway rises to its higher levels due to the line-of-sight clarity between the transmitter and victim receiver; thus showing an increase in required geographical isolation. With 15 m and 10 m antenna heights, 15 km and 3.4 km are necessary, correspondingly, whereas the mandatory physical isolation for the antenna height of 5 m reduces to be 2.3 km only.

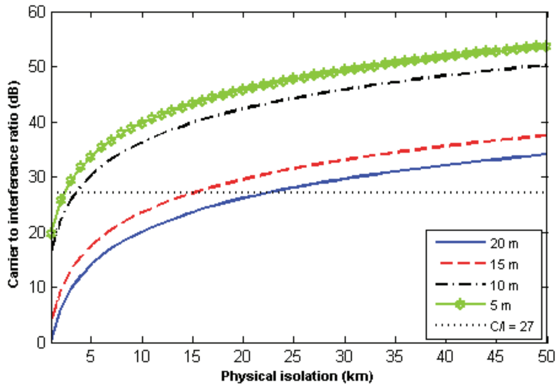

Fig. 6. Separation distance for different antenna heights.

4.2 Statistical Results

Although fixed point-to-point service can be directly judged by deterministic methods used in Section 4.1, but by statistically altering selected variable attributes, systems sharing capabilities can be improved. Accordingly, Monte-Carlo approach is applied for different FSS antenna elevation, and HAPS gateway antenna height [18]. During the sampling, stations remain fixed and geographically separated by 5 km. In Fig. 7, Monte-Carlo simulation remarkably distinguished the FSS antenna elevation technique by attaining low interference probability.

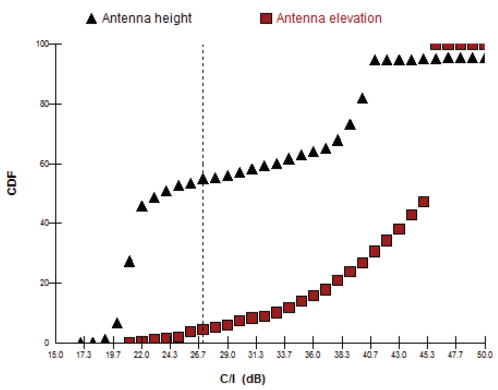

Fig. 7. Statistical simulation for different antenna elevation and height.

The process starts by choosing attributes limitation. For instance, the FSS elevation angle and HAPS gateway antenna height random sampling attributes are from 5° to 90°, and 0 m to 30 m limitations, respectively. In fact, the interference probability gives an approximation of unsatisfactory trials over the total number of trials. For a fastest numerical calculation, Monte-Carlo variable is chosen to distribute uniformly, for a number of samples of (N), then each sample of order ($i = 1, 2, \ldots, N$) should have the same probability of $P(xi) = 1/N$. Therefore, interference probability of all the unwanted range is equivalent to $\Sigma P(xi)$. The cumulative in probability increases as the number of trials increase. Giving that $\Sigma P(xi)/ P(xi) = i$ should define the number of the last unwanted trial if the range starts from $x_{\min}$, otherwise i defines the first number of the unwanted trial until $x_{\max}$.

To transform the 59 % interference probability to an unwanted range of antenna heights, a trial number of $i = 29.5$ is returned. Subsequently, it defines $x = 17.4$ m, and since the unwanted range is up to 30 m antenna height, consequently, the unwanted range falls within (30 – 17.4 = 12.6) m until 30 m antenna height. In parallel, antenna elevation produces 16.3 % CDF; which returns the trial number $i = 8.15$ yield an attribute of 18° antenna isolations. This can be translated by an unwanted range of parameters from 5° until 18° for the antenna elevation technique. Hence, the statistical results conclude that choosing mitigation parameters using MC allows the two communication systems to coexist; by avoiding the unwanted range of parameters and thus avoiding interference.

5. Conclusion

Spectrum sharing between HAPS gateway link and FSS in the band 5850 – 7075 MHz needs essential coordination rules. The methodology proposed is based on enhancing the MCL approach, which justified the technical compatibility between FSS and HAPS systems earth stations. The different coordination possibilities and interference mitigation techniques have shown the capabilities to compensate for the large required separation distance under MCL.

Acknowledgements

This work is under the Post Doctoral Research Fellow scheme provided by the Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM).

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